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Coordinated Management for Harvesting, Storing, and Marketing Northwest Apples

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IMPORTANCE OF A HIGH-QUALITY PRODUCT

The cost of producing apples in the Pacific Northwest and transporting them to distant markets is relatively high. The fruit commands premium prices, however, because of its quality, attractiveness, and uniformity of size. The fruit industry in this area therefore depends upon the maintenance of a high-quality product. Several factors affecting the industry as a whole have a bearing on the problem of improving this quality and of maintaining the fruit in good marketable condition for the ultimate consumer. For instance, the volume of production and the long marketing period make it necessary to regulate the temperatures during both storage and long-distance transit.

Methods of marketing and distribution often do not adequately provide for maintaining apples in the best condition—"condition" referring to those elements of fruit quality that are influenced by methods of handling or storage. Thus, delivering a first-grade product to the consumer is imperative, yet complicated by several conditions that, at the present time, are difficult to control. Commodity competition, as it may be expected to develop in the postwar period, and the perfection of quality standards by other fruit-producing districts emphasize the importance and significance of the problem of fruit condition.

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[1] The authors wish to acknowledge the cooperation of the growers, officials, and employees of the Oroville Independent Growers, Inc.; L. O. Solberg, architect; Edwin Smith, senior horticulturist, Bureau of Plant Industry, Soils, and Agricultural Engineering; and William Stone, refrigerating engineer, without which these studies could not have been carried on effectively.

More than half the apples produced in north-central Washington are the Delicious variety. This is the one upon which growers must depend to maintain the reputation and market of the Northwest apple districts. These apples, however, are most sensitive to storage and handling conditions.

This report, based upon tests covering a period of 2 years, presents the results of a planned procedure of harvesting, packing, storing, and marketing apples as undertaken by a cooperative association of growers in Oroville, Wash. It includes the building plan and arrangement, the plan developed for handling the apples, the tests and results, and the observations on improved storage facilities designed to meet the particular requirements of the association on a practical basis.

To establish procedure for getting fruit of desirable condition and of high quality it is important at this point to set forth the requirements that must be observed. Various authorities[2] show that apples, particularly Delicious, that are to be held in storage and marketed late should be harvested at optimum maturity from healthy vigorous trees and from heavy uniform crops. They should be placed in cold storage within 24 hours and cooled to 30° to 32° F. core temperature within a week. During the storage period this temperature and 85 to 87 percent relative humidity should be maintained. When the apples are packed, either during harvest or storage, poor-condition and low-grade fruit should be marketed immediately.

During transit to market, the fruit should be placed in refrigerator cars and kept at 30° to 32° F. Although it is sent to markets that vary widely in the quality and adequacy of storage facilities, it is important to hold the fruit at optimum temperature until actually consumed.

Handling all fruit in this manner would be ideal, of course, but since this is frequently impractical it is important that these requirements first be fulfilled for fruit that is to be held in storage for late shipment.

Typical Commercial Procedure

Observance of standard handling requirements varies widely within the industry. Presenting a typical commercial procedure will illustrate some of the difficulties that led the Oroville growers to develop a definite plan for coordinating their harvesting, handling, storing, and marketing.

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[2] Fisher, D. F. handling apples from tree to table. U. S. Dept. Agr. Cir. 659, 39 pp., illus. 1942.

Hukill, W. V., and Smith, E. cold storage for apples and pears. U. S. Dept. Agr. Cir. 740, 61 pp., illus. 1946.

Rose, D. H., Wright, R. C., and Whiteman, T. M. the commercial storage of fruits, vegetables, and florists' stocks. U. S. Dept. Agr. Cir. 278, 52 pp. (Revised.) 1942.

As the fruit is picked it is placed in boxes under the trees and then hauled to storage or packing plants as space permits. Fruit remains in the orchard for variable periods—some for as long as 3 to 4 weeks. Temperatures at this time of year usually are sufficiently high to promote rapid ripening after picking.

As the fruit is hauled to storage by truck or orchard trailer it is received either into cold storage, common storage warehouses, or directly into the packing room. Packing facilities are seldom adequate to pack all the fruit during the harvest season. In fact, most packing operations cover a period of 3 or 4 months, while the fruit is usually picked in 4 or 5 weeks.

If cold-storage space is available the loose fruit in excess of the packing capacity is refrigerated. Some effort is made to select for this treatment the fruit that is intended for late shipment. Apples for which there is neither storage space nor immediate packing facilities must remain in the orchard until other lots are shipped. In addition to inadequate cold-storage space for all fruit, there is usually insufficient refrigeration capacity to maintain a 32° F. temperature during the time the fruit is received. In many cases, a fruit temperature of 32° is not obtained for 6 weeks after the fruit is put in cold storage.

As the fruit is packed it is either shipped immediately to market or placed in storage. Since the marketing season for Delicious usually extends into March and April, a large volume of fruit must be placed in storage for variable periods.

Fruit is taken into packing or storage plants on belt or roller conveyors through window plugs or is hand-trucked through open doorways. It is also conveyed or hand-trucked to the grader. In packed containers it is segregated according to size, grade, and variety and placed in storage. Hand trucks or conveyors are used to load the fruit into refrigerator cars for shipment to market.

The railroad companies provide a number of protective services for fruit in transit. Depending upon the condition of the fruit and the weather, the shipper specifies the service he desires. Since optimum conditions cannot always be provided or maintained, it is important that the fruit be in the best possible condition at the time it is shipped.

Interrelation of Handling, Storing, and Marketing Processes

The requirements for keeping apples in good condition have been outlined rather simply. The practical difficulties in meeting these requirements continually interfere with accomplishing the simple objectives—prompt cooling, careful handling, and maintaining low temperatures in storage. The operations involved in producing and marketing 15,000 to 20,000 carloads of apples each year from the Wenatchee-Okanogan district represent compromises between what ought to be done if conditions would permit and what can be done in the existing circumstances.

It might appear that providing ample cold-storage space would assure first-class condition for all the fruit, or that a certain marketing program would result in all fruit reaching the market before it has passed its prime, or that good orchard practices and prompt handling at harvesttime would eliminate troubles arising from advanced ripening. Attention to any single phase of the problem, however, cannot guarantee the necessary top condition.

The effectiveness of a marketing program, for example, depends upon facilities for proper handling and storage as well as upon having fruit of high quality. The cold-storage facilities in turn can be operated effectively only when they are planned in conformity with specific conditions of production, transportation, management, and marketing. A cold-storage plant that gives satisfactory results under one set of circumstances might not be suited at all to others. For this reason the design of a cold-storage plant is not solely a problem of assembling equipment and storing the fruit. The plant design is a part of a plan for controlling the condition of fruit until it is eaten. The other parts of the plan include producing the fruit, harvesting and getting it to storage, packaging it, sorting or segregating, shipping, and distributing it for consumption.

These operations are often undertaken without planning being recognized as such, and consideration of the relation between processes is completely neglected. All fruit from a group of growers, for instance, may move into storage and lose its identity. This would include fruit picked early and that picked late; fruit from the healthy, heavily loaded trees and that from weak or lightly set trees; and fruit moved promptly to storage and that left in the orchard for several days after picking. If the marketing plan is entirely independent of the harvesting and storage operations, the fruit sold early in the fall will be more or less indiscriminately chosen and will include some that may not yet be in the best eating condition. The fruit held for late shipment will include some that is past its prime and in no condition to be stored for a long period.

On the other hand, if a storage plant is designed for receiving and holding the fruit from growers who have specific production, harvesting, and marketing problems, if the marketing plan is coordinated with the limitations of the plant and the practices of the growers, and if growers using the plant will adjust their demands to the capacity of the plant and to the requirements of their marketing schedule, the fruit marketed throughout the season will be of good condition. Only by such coordination can limited facilities give the most effective results.

REFRIGERATED STORAGE

A survey of cold-storage facilities in the Wenatchee-Okanogan district as of 1941[3] indicated that most localities did not have sufficient facilities for cooling the fruit to 30° to 32° F. within the desired short period required to maintain it in good condition until mid- or late-season shipment. This was especially true in those localities producing a high proportion of the Delicious variety. The shortage of cold-storage space was caused by a prolonged period of low fruit returns—since 1930 little additional capacity had been added, while the need had increased.

Although there was no general increase in total production over the previous decade and although several thousand acres of bearing trees had been removed, a definite change in storage requirements had developed. Orchards removed were generally old ones of varieties other than Delicious. Orchards increasing in production were in most cases Delicious. Thus the requirements of cold storage had gradually changed, so that more than 50 percent of the crop was of a variety that is highly perishable, that should be picked within a 15-day period late in September or early in October when day temperatures are normally high, and that promptly after picking should be placed in cold storage where the temperature could be quickly reduced to 32° F.

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[3] HUKILL, W. V., and SMITH, EDWIN. SUMMARY OF SURVEY IN WENATCHEE-OKANOGAN DISTRICT OF WASHINGTON. 15 pp. U. S. Bur. Plant Indus. and U. S. Bur. Agr. Chem. and Engin. 1941. [Processed.]

The increased production of Delicious has also lengthened the time in which this perishable variety is marketed. As the storage period is increased, the necessity for prompt cooling is increased and more care has to be exercised in harvesting the fruit at the correct stage of maturity.

As economic conditions improved generally and returns to the growers from sale of their fruit increased, one of the first requirements to be recognized was the need for additional cold storage. To meet this, the industry has been building new storages and improving existing facilities.

COOPERATIVE ORGANIZATION PLANS

One of the groups undertaking the construction of new cold-storage facilities was the Oroville Independent Growers, Inc. This cooperative association constructed a new cold-storage and packing plant in 1943. The growers wished to take advantage of all principles of construction and methods of fruit handling and storage that would enable them to market their apples in the best possible condition. In their packing and storage facilities they incorporated features of construction that would, it was hoped, give them maximum protection for their fruit and at the same time permit efficient and practical operation. Since some of these features had not been in general use before, it was desirable to perform some tests to determine their value.

The members and management of the Oroville association were aware that the provision of adequate, or even superior, facilities would not necessarily insure their having apples that would be in the most desirable condition when marketed. They realized that much attention should be given to harvesting and delivery procedures. On the basis of this interest and spirit of cooperation, it was decided to make as careful a study as possible of the practical operation of their fruit harvesting and handling program in addition to tests on the operation of the cold-storage plant.

FRUIT SEGREGATION

The first step in the handling program was to determine prior to harvest which fruit would be shipped to market early, which intermediate, and which late in the season and to give it handling and storage treatment accordingly. Like most organizations, this association did not have facilities sufficient to care for all the fruit of its growers in a manner necessary to insure high quality for the late market. It was necessary, therefore, to withhold some of the apples from prompt refrigeration in order to give proper attention to those intended for late storage. The fruit was classified according to quality and condition at time of harvest and of packing. Only the very best fruit was to be held for late storage, and that of potentially poor storage quality was to be shipped to market immediately while still firm and crisp. Apples shipped during the intermediate season would include only those that were of high quality at harvesttime but that could not be given optimum handling and storage treatment.

The objectives of this method of fruit classification and preharvest planning of treatment and procedure were as follows:

1. Getting high-quality fruit to market throughout the season.
2. Maximum use of refrigeration.
3. Rapid and uniform cooling of fruit for late shipment.
4. Efficient use of storage space, warehouse labor, and equipment.
5. Simplification of warehouse operation and procedure.

It was anticipated that a number of operational problems would be encountered and that these could be met fully within the association only by a high degree of cooperation of growers, management, and employees. A thorough understanding of the program and its objectives was necessary.

STORAGE FACILITIES

This organization had to start from the ground up in laying out its plans. Both packing and storage facilities were needed, and with a prospective crop of about 115,000 packed boxes, some of which would be sold before harvesting was completed, it was decided to build the storage plant to hold 80,000 boxes. This left a substantial quantity of fruit to be held either in common storage or in commercial cold storages other than in the new plant. For the most part, fruit of the late-maturing Winesap variety was to be sent to common storage until space was available in the cold storage. While this was a temporary arrangement until additional storage could be built, the plan was to provide at this time sufficient storage and cooling capacity for the Delicious that was to be held for the winter market.

The building site was chosen to permit future expansion, and the floor plan was such that a later addition could be made without introducing operational difficulties. In considering the general lay-out of the building, an attempt was made to accommodate all the necessary functions and yet conform with the plan of operation to be followed in using the building. These functions were outlined as follows:

1. Accommodate the fruit traffic—
    - *a.* From truck to storage room.
    - *b.* From truck to packing room.
    - *c.* From packing room to storage room.
    - *d.* From storage room to packing room.
    - *e.* From packing room to railway car.
    - *f.* From storage room to railway car.
    - *g.* Within storage rooms.
    - *h.* Within packing room.
2. Accommodate other traffic.
    - *a.* Grower and packing supplies from railway car or truck to storage.

- *b.* Grower supplies from storage to truck.
- *c.* Packing supplies from storage to packing room.
- *d.* Disposal of empty boxes from packing line.
- *e.* Disposal of culls from packing line.

3. Provide necessary services to the building.
   - *a.* Office located for convenient communication.
   - *b.* Sanitary facilities for workmen.
   - *c.* Engine room and power center.
   - *d.* Shop and utility storage.
   - *e.* Brine spray and fan room.
   - *f.* Air-distribution system.
4. Provide for operational requirements.
   - *a.* Space for fruit segregation.
   - *b.* Storage for fruit.
   - *c.* Storage for grower and packing supplies.
   - *d.* Insulation and construction to conserve refrigeration.

These requirements, the cost of alternative ways of meeting them, and the limitations on availability of materials and services were used as a guide in the building arrangement. The relative importance of each item was decided upon by the way it affected the plan of fruit handling. For example, the fruit for long-season storage was to be brought to the plant as early in the day as possible and placed in cold storage immediately for packing later in the season. It was necessary to get this fruit off the trucks without delaying the unloading of other lots that were to be packed immediately. Plenty of unloading space was needed.

The building as constructed contains a packing room and four cold-storage rooms, two on each floor (fig. 1). The inside dimensions of each storage room are about 98 by 68 feet. The packing room, 20 by 220 feet, is on the upper floor, running lengthwise of the building, and on the opposite side of the storage from the railroad siding. Unloading platforms are at both ends at the upper floor level.

Fruit may also be unloaded into the basement rooms from the packing-room side by inclined belt conveyors passing under the packing room. Apples to be precooled before packing are unloaded on these conveyors. Fruit going directly to the packing machine and that going to temporary storage and limited refrigeration on the upper floor is unloaded and conveyed on hand trucks.

Conveyors were installed for moving the fruit from the packing room to the storage rooms and for moving loose fruit from storage to the grader. A single conveyor line (figs. 1 and 2) begins at the lidding press near the west end of the packing room, extends to the center line of the adjacent storage room, traverses a few feet along the center line, then goes through the floor to the room below. From there it continues along the center line of the storage rooms into the other basement room and again passes through the floor to the storage space above. Here it turns again toward the packing room and ends at the fruit washer at the beginning of the packing line. Passing through each storage room the conveyor can carry packed boxes from the packing room to any storage room and at the same time, if necessary, can carry precooled fruit loose in boxes from storage to the washer. Packed boxes can be intercepted for loading directly into a car or for segregation at any point in the conveyor system. The conveyor is made

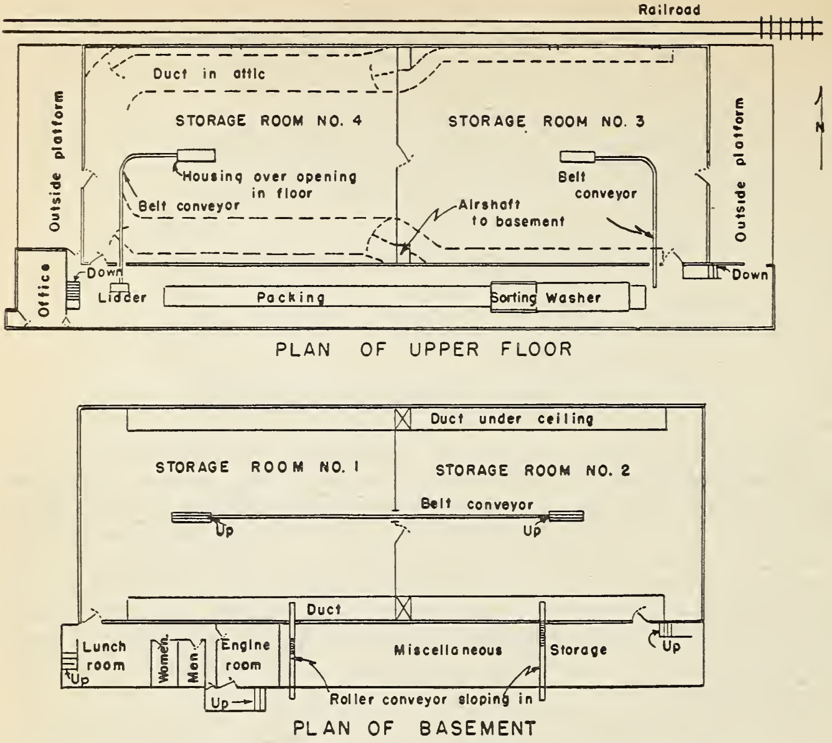

FIGURE 1.—General plan of cold storage, showing location of storage rooms, packing room, service rooms, conveyors, openings, and air ducts.

up of independent segments, any one or all of which can be reversed to facilitate handling.

The office is at the west end of the packing room and adjacent to the storage room, that is used during summer months for grower supplies. The engine room is in the basement, below the packing room. Here it is accessible for repairs and does not require space that might be used for storage, nor does it interfere with fruit traffic or air distribution. The brine spray chamber and air blower are on the roof. Where there is sufficient room for the equipment this makes the air ducts leading to the storage rooms relatively simple.

The storage building is of reinforced concrete. Departure from conventional construction was made only when necessary on account of wartime shortages of materials or the design requirements of the building. The basement was excavated to the depth required for

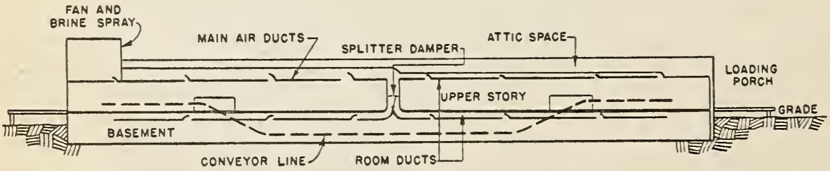

FIGURE 2.—Longitudinal section of storage, showing conveyor and air ducts.

loading to and from cars on the upper floor level. The railroad siding was on a slight grade so it was necessary to compromise on the height of the floor level. In relation to floor level, the cars at one end of the building are a little lower than those at the other. It is most convenient to load a car when the storage-room floor is about level with that of the car. Most of the fruit was loaded onto railroad cars through doors near the center of the building so the relative level of the floors proved satisfactory.

A 4-inch concrete slab was used for the ground floor, underlain with 6 inches of pumice gravel for insulation. Twelve inches would have been used if transportation and other handicaps had not been encountered.

This material was available in the area. The ground-water level is but a few feet below the surface at the site so the problem of keeping the pumice dry was considered. There are very few data, however, on the effect of capillary moisture on heat penetration through a ground floor, so the pumice was laid directly on the ground except in a small section of floor that was installed for testing purposes.

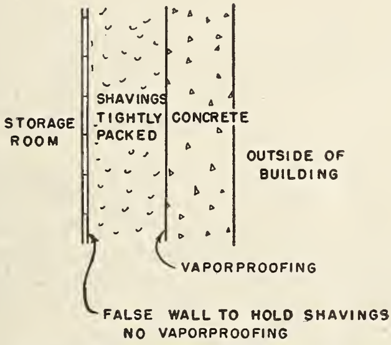

Figure 3.—Section through outside wall, showing location of vapor barrier.

Thermocouples were embedded in the earth, pumice, and concrete in this and in an untreated section. Temperatures measured within the floor over two seasons of operation showed that the exclusion of moisture in this way has substantially contributed to keeping the pumice insulation effective. Records of this test are discussed in more detail on page 26.

The outside walls were insulated with mill shavings 12 inches thick, by erecting a false wall 12 inches from the inside of the concrete wall and filling the space with shavings packed tightly (fig. 3). The ceiling was covered with shavings 18 to 24 inches thick. Twelve inches of shavings is equivalent to about 8 or 9 inches of most commercial insulating material,[4] so since shavings were available locally they seemed the most economical material to use. The intermediate floor was also insulated with shavings. In some plants insulation between stories is not necessary, but in this one it was anticipated that for a short period each season only one floor would be refrigerated.

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[4] American Society of Refrigerating Engineers. refrigerating data book. v. 1 and 2. 1942.

Part of the upper floor might be kept warm and used for handling grower supplies while there was still some fruit in the basement.

Shavings is a good insulating material if packed tightly, so that it does not settle enough to leave gaps in the insulation, and if kept dry. Any insulating material must be kept dry to be effective. A well-built concrete wall and a good roof protect it against penetration of rain. In this plant, as in most apple storages, no water was to be used inside the storage rooms. Wetting from the inside, therefore, was not the problem that it is in many cold-storage plants not used for apples exclusively. The only remaining source of moisture accumulation in the wall insulation would be condensation of vapor that might penetrate concrete or most other building materials from the outside.

Unless dealt with in the construction, moisture may condense in the cold parts of the insulation and reduce its effectiveness. In general, water vapor tends to move from a warm to a cold area and condense. As the walls are warmer than the storage room, there is little tendency for vapor to move from the room to the walls. They are colder than the outside air, however, and vapor from the outside air may collect within the insulation. In the Oroville plant this tendency was checked by applying two coats of asphalt to the inside of the concrete wall (fig. 3). No such vapor barrier was applied on the storage side of the shavings, so that what little vapor penetrated the asphalt-coated concrete could pass on through the insulation into the storage room and eventually appear as a deposit of water or frost on the cooling coils.

The same tendency for condensation occurs in the roof insulation, but mopped asphalt roofing will prevent most of the vapor from penetrating through the roof. Some may come through the walls into the attic space over the shavings, but this is minimized by keeping the attic vents tightly closed when the inside of the building is cold. This space may be ventilated early in summer before the refrigeration is turned on. When the ceiling insulation was installed, plain resin rather than vaporproof paper was used under the shavings to prevent their sifting through the ceiling. This resin paper does not hinder the flow of vapor into the cold room, so there is a continuous tendency for any moisture in the shavings to move into the room below.

As already indicated, conveyors move boxes within storage rooms and between storage rooms and packing plant. Since hand trucks are more convenient under some conditions for unloading trucks and moving fruit into storage, provision was made for using them as well as conveyors. Small insulated openings, known as fruit plugs, were installed in the storage walls of the upper-floor rooms at the ends of the conveyor lines.

To prevent air from readily passing through the opening a canvas flap may be installed. This curtain immediately falls back in place after the box has moved through. When hand trucks are used, full-size doors must be open, permitting a large quantity of warm air to enter and cold air to escape. It is difficult to keep storage temperatures low under these conditions. To minimize the loss of refrigeration in the Oroville plant, light bump doors were installed. They are bumped open by hand trucks and swing closed after each has passed.

The compressor room does not communicate directly with the storage space, so should an accident occur, there would be little hazard from ammonia penetrating to the storage rooms. The compressor room was made large enough to accommodate more equipment if it should later become necessary to increase the refrigeration capacity. A well from which cooling water for the ammonia condenser is pumped was dug only a few feet away from the condenser. As the cooling water leaves the condenser, it is piped to the boiler, where it is heated and used for hot solutions in the apple washer. The plant has city water connections, and in an emergency all water requirements could be supplied from this source.

REFRIGERATION CAPACITY

The capacity of the refrigerating equipment was based not only upon the size of the building and the quantity of fruit to be stored, but also, and largely, upon the rate at which the fruit would be brought to the plant for cooling.

It is estimated that about 6½ tons of refrigerating capacity is needed for each 1,000 boxes of loose fruit brought into the plant daily. This is in addition to that required to absorb the heat that enters continuously through the walls, floor, and roof and that generated by the blower and motors. The anticipated daily receipts of fruit were estimated at 5,000 loose boxes, 4,000 of which might be put under refrigeration. Thus, the refrigeration requirement for fruit cooling alone was calculated to be 26 tons.

Total refrigeration required was estimated as follows:

	Tons
Walls:	
Area: 20×270×2=10,800 square feet.	
Refrigeration loss: 10,800÷11,000	1.0
(Insulated with 12 inches of shavings, each 11,000 square feet of wall will lose about 1 ton of refrigeration under ordinary conditions of apple storage in this climate during the last part of summer. If the insulation is thicker, the area losing 1 ton will be proportionately larger.)	
Roof:	
Area: 200×70=14,000 square feet.	
Refrigeration loss: 1½ feet of shavings: $\frac{14,000}{1\frac{1}{2}\times 11,000}$	0.8
Floor:	
Area: 200×70=14,000 square feet.	
Refrigeration loss: 14,000÷10,000	1.4
(With 6 inches of dry pumice as insulation, 10,000 square feet of ground floor may be expected to lose about 1 ton of refrigeration. The ground under the pumice is much cooler than the outside air.)	
Heat generated by blower and motor:	
Horsepower of fan motor: 15	
Refrigeration required: 15÷4	3.8
(About 1 ton of refrigeration is required to remove the heat generated by each 4 hp. developed by continuous operation of motors.)	
Cooling fruit:	
Refrigeration required	26.0
Total	33.0

These estimates include the heat from respiration of the apples while they are cooling but not that generated by the apples after reaching the storage temperature. At 32° F. Delicious apples will generate enough heat for each 14,000 packed boxes in storage to require about one additional ton of refrigeration. During the time fruit is being received at the highest rate, the plant is usually not filled to capacity.

Other items increasing the refrigeration requirement are the heat generated by lights, conveyor and other motors, and workmen, and the warm air entering through open doors. These items are not included in the estimates, but they do increase the refrigeration demand. The load they impose cannot be anticipated exactly, but they emphasize the importance of considering as a minimum the estimates of refrigerating capacity given above.

When the plant was being built, wartime conditions made it impossible to get equipment to meet design requirements. One used and one new compressor were obtained. Together these gave almost the required capacity in about the right ratio—one-third in one machine and two-thirds in the other. In this way, by running either or both compressors, three stages of capacity were available. It was impossible to get automatic control on the smaller one, which was a handicap in operating because it had sufficient capacity for holding storage temperature during most of the season.

The central brine spray chamber with a large central fan was chosen for cooling the rooms. As the air is forced past them the cooling coils are sprayed continuously with a solution of salt that keeps water from freezing on the coils. The air is cooled by contact with the pipes and the small particles of brine. The moisture condensed from the air as it returns from the storage rooms combines with the brine. This system can supply the necessary cool air to any room or rooms, a feature essential to the growers' arrangement, because fruit to be held late in the season can be given the required refrigeration at harvesttime.

It is customary to provide blower capacity for circulating 1,000 cubic feet of air per minute for each ton of refrigerating capacity, so about 30 tons calls for circulation of 30,000 cubic feet per minute. Since this plant was intended to cool the fruit quickly and maintain a uniform temperature, a larger fan was installed. By running the fan at a relatively slow speed, 30,000 cubic feet per minute could be provided. By increasing the speed, the volume could be increased to 50,000 or more. A "load limiting" fan, one with the blades tipped backward, was chosen because if the valves, which were to be installed for reversing the air direction, should open partially and fail to close, this fan would not require excessive power. There is little chance of this happening, but if it should a "non-load-limiting" fan might seriously overload the motor.

The air-circulation system was designed for rapid cooling of the fruit. Since Delicious apples constitute a large percentage of the crop, the first objective of the organization was so to handle and store them that only first-class fruit would be shipped throughout the season. In order to keep this variety for winter shipment it must be cooled quickly to 30° to 32° F. and that temperature maintained during storage. The nearer these apples can be kept to their freezing temperature[5] without actually freezing, the better they will store.

Even when a large volume of air is circulated, the cold air entering the storage room warms appreciably before it is returned to the cooling coils. This means that in order to prevent freezing near the delivery ducts, the fruit temperature in some parts of the room must be well above the freezing point. To avoid this temperature difference in the fruit in various parts of the room, the air system was designed to reverse the direction of air flow periodically. Cold air is driven from a duct on one side of each room and returned to a duct on the other side. After 3 hours of operation, a set of automatic dampers changes the direction of the flow so that the cold air enters the room from the duct that was formerly acting as a return and moves across the room in the opposite direction. In this way fruit on both sides of the room is exposed equally. The time between reversals may be set as desired, but it was found in the Oroville plant that with the direction of air flow reversed every 3 hours, the temperature of the fruit was satisfactorily uniform.

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[5] WRIGHT, R. C. THE FREEZING TEMPERATURES OF SOME FRUITS, VEGETABLES, AND FLORISTS' STOCKS. U. S. Dept. Agr. Cir. 447, 11 pp. 1937.

One way of cooling the fruit more quickly is to introduce air at a temperature well below the freezing point of the apples. This results in some freezing in boxes nearest the air delivery when such cold air is blown upon them continuously. For this reason it is not practical to use air temperatures below 28° or 29° F. in the ordinary storage with a one-way air system. When the air direction is reversed periodically, none of the fruit is exposed continuously to the coldest air, so that colder air can be used without danger of freezing.

A certain amount of air pressure must be developed by the blower in moving air through the system. If the ducts are small or if there are unnecessary turns in the air path or if the openings for passage of air into or out of the ducts are small, high pressure is required to move the air.[6] The total volume of air delivered by the fan decreases as this pressure increases. Also, the power required to move a given volume of air is increased with increased pressure. For this reason the ducts in this plant were made large, and no lateral ducts were used in the storage rooms.

The size of ducts installed is governed by the volume of air to be circulated. It is good practice to make the ducts of such size that the average air velocity does not exceed 1,000 feet per minute. Making them larger would reduce the pressure on the blower but would also take space that might otherwise be occupied by more fruit. In this plant the room ducts and the main duct were constructed for an average air velocity of 1,000 cubic feet per minute when 30,000 cubic feet was being divided equally among the rooms. It was intended, however, to use a larger volume, at least some of the time, and to concentrate the air in certain rooms part of the season. For this reason the velocity in some ducts might occasionally be considerably greater than 1,000 feet per minute.

The inside of each duct was as smooth as possible and the turns were streamlined to prevent excessive resistance. Two main trunk ducts carried the air to or from the center of the building, where it was distributed to the rooms (figs. 1 and 2). Each room had two ducts, one along the ceiling at each side wall. Where the air was divided, part of it leaving a main duct to enter a room duct, splitter dampers were installed to direct the air around the turn. The dampers were adjustable and served to apportion the air as desired. They could be swung to the extreme positions to divert all or none of the air to any room.

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[6] AMERCAN SOCIETY OF HEATING AND VENTILATING ENGINEERS. HEATING, VENTILATING, AIR CONDITIONING GUIDE, 1943. Vol. [ed.] 21, 1,160 pp. illus. New York. 1943.

An air-distribution system in which the air is released from one side and moves across the room to be returned at the other side (figs. 1 and 2) has several advantages over a multiple-duct system: (1) It is usually less expensive to install; (2) fewer turns and fewer small air channels make it possible to handle the air with less pressure; (3) the air is delivered at the side walls where workmen spend the least time—working conditions are more comfortable if it is not necessary to pass continually through drafts set up by cold air blowing out of ducts over main aisles; (4) the most important advantage is that moving the air across the full width of the room between delivery and return ducts creates a velocity greater than if the same volume of air were moved only a few feet—higher velocity removes the heat from packages more readily and uniformly.

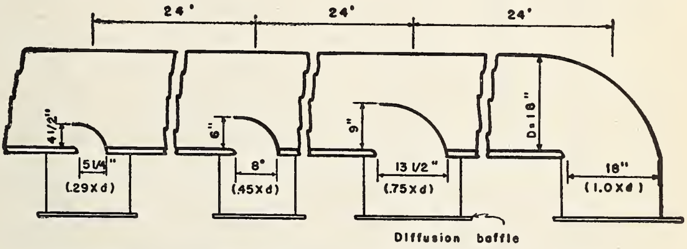
It might appear that air moving all the way across the room will warm up more by the time it reaches the return duct than if it is introduced at numerous points and moves over relatively short paths to nearby ducts. That this is not the case can be understood by considering the quantity of heat to be carried away and causing the rise in air temperature. The heat to be removed is of a definite quantity, fixed by various sources. When a given volume of air passes through the room, its temperature will rise just enough to carry off this heat. Now, if by increasing the length of travel, the same volume of air would increase the temperature rise, then the quantity of heat carried off also would be greater. The heat generated, however, has not been increased, so the higher temperature rise cannot be maintained. The length of air path or method of distributing the air, therefore, cannot result in a higher rise in air temperature unless the volume of air is decreased or the quantity of heat picked up is increased.

In the conventional air-distribution system, one duct or set of ducts is exclusively for delivery and another is exclusively for return. The size and arrangement of openings in each delivery duct can be laid out without regard to what might happen if it were used as a return; in like manner the size and arrangement of openings in the return ducts can be adjusted for return air only. When a duct is used for delivery, the air has a tendency to move past the first opening and to leave more readily from openings farthest from the source. To compensate for this, the near openings may be made largest. On the other hand, when a duct is used as a return the air enters more readily into openings nearest the fan. This effect may be counteracted by making the near openings smallest. Thus, the gradation in size of openings in delivery and return ducts is directly opposite. When the same duct is used alternately for delivery and return, it is readily understood that gradation of openings along the duct cannot give uniform flow for both operations.

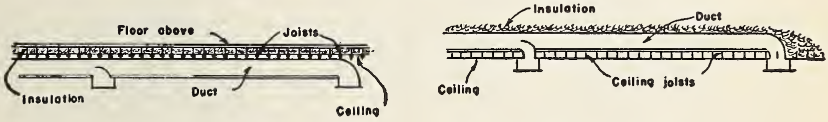
To permit using either duct alternately for delivery and return, both must have the openings designed to give uniform flow under either condition. This requirement was met in the Oroville plant by grading the opening size so that when the duct was operating as a return, all openings would draw in the same quantity of air regardless of location along the duct. To get uniform distribution among openings when the duct was acting as a delivery, each was fitted with a curved scoop that projected into the duct far enough to intercept and exhaust the appropriate air volume. A diagram of duct openings suitable for a reversed air system is shown in figure 4, *A*.

The dimensions shown provide approximately uniform distribution, but it may be necessary to adjust the height of the deflectors inside the duct after installation. Measuring the air discharge is a guide to adjustments. Observations in another plant using these dimensions showed a tendency for too large a proportion of the air to move to the farther openings during discharge; to correct this the deflectors were raised. While the dimensions shown in table 1 provided uniform fruit temperatures in the Oroville plant, a more exact formula should be developed for general application.

In the Oroville plant the openings in each duct are about 24 feet apart and each is the full width of the duct. The edges of the openings are curved to avoid high resistance. This may be done with a curved piece of sheet metal or wood molding. In the upper storage rooms the ducts are on top of the ceiling joists (fig. 4), so the air must turn at the opening and move through the 8-inch thickness of the ceiling before it is released into the room. When air is coming out of an opening it is moving relatively fast. If it were not checked it would tend to move down to the floor or to the top of the fruit stack and splash in all directions from there. It should spread horizontally from near the ceiling.



A- LONGITUDINAL SECTION OF AIR DUCT FOR REVERSIBLE AIR CIRCULATION



B- DUCT APPLIED UNDER CEILING

C-DUCT APPLIED OVER CEILING

FIGURE 4.—Air ducts for reversible air flow. *A*, Duct with graduated openings—for dimensions at openings see table 1. *B*, Section applied under ceiling, as in basement rooms. *C*, Section applied over ceiling, as in top-story rooms.

Diffusion baffles were hung under each opening in a horizontal position in the Oroville plant so that the air as it comes out of the duct openings is diverted over the tops of the boxes in every direction, to cool the fruit between openings. Such a baffle should be far enough below the opening to permit free movement of the full volume of air. Its shape and its proper distance below the openings to provide best distribution are yet to be determined. Perhaps curved instead of flat baffles would be more effective.

TABLE 1.—*Length of each opening and height of deflector vanes in a rectangular duct used alternately for air delivery and return*

[N=Narrowest dimension of duct cross section; D=depth of duct; when width is greater than depth, then N=D]

LENGTH OF OPENING

Spacing	Opening—No. 1 is farthest from fan							
	1	2	3	4	5	6	7	8
2×N	1. 0×D	0. 95×D	0. 82×D	0. 65×D	0. 50×D	0. 39×D	0. 31×D	0. 26×D
4×N	1. 0×D	. 90×D	. 71×D	. 51×D	. 39×D	. 29×D	. 23×D	. 19×D
8×N	1. 0×D	. 85×D	. 58×D	. 39×D	. 28×D	. 21×D	. 16×D	. 13×D
12×N	1. 0×D	. 79×D	. 50×D	. 32×D	. 23×D	. 17×D	. 13×D	. 11×D
16×N	1. 0×D	. 75×D	. 45×D	. 29×D	. 20×D	. 15×D	. 12×D	. 095×D
20×N	1. 0×D	. 71×D	. 41×D	. 26×D	. 18×D	. 13×D	. 10×D	. 085×D
HEIGHT OF DEFLECTOR VANES								
Distance above opening	D	½D	⅓D	¼D	⅕D	⅙D	⅐D	⅛D

In an apple storage, uniformity of temperature depends upon circulation of air in equal quantities to all points in the room. In a conventional room the girders supporting the ceiling joists usually extend downward in such way as to block free air circulation across the space over the boxes. When they do, areas between the girders frequently receive little circulation and the temperature there stays too high. This is avoided in the Oroville plant by providing free space across the ceiling.

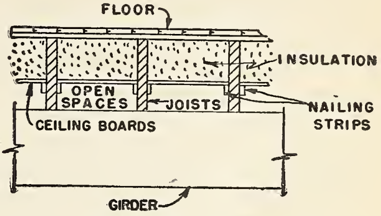


Figure 5.—Method of providing air-circulation space over girders under ceiling.

On the upper story the ceiling is built flush with the bottom of the girders so that there are no interfering structural members. Since the ceiling of the lower story acts as the floor of the upper story, the joists are set on top of the girders to carry the floor load. This leaves the girders below the natural ceiling line. If this floor had not been insulated, the ceiling could have been omitted and the air, which moves crosswise of the girders, would have moved freely over the tops of the girders through the spaces between joists. Instead of being placed across the bottom of the joists the ceiling boards were inset into the joist spaces about 4 inches above the tops of the girders, and shavings were filled in above these boards (figs. 4, *B*, and 5). This left a clear space 4 inches deep over each girder and between all joists to permit the desired free cross movement of air, thus eliminating any traps or pockets of stagnant air between the girders.

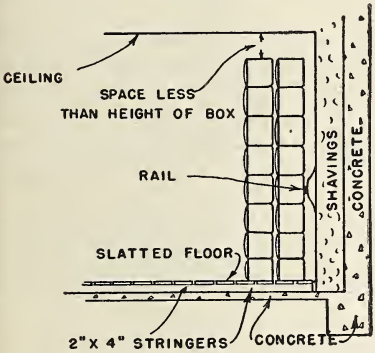


Figure 6.—Section through room, showing slatted floor rack, wall rail, and ceiling clearance.

The ceiling height on the lower story was established to permit stacking eight boxes and leaving a clearance of about 10 inches between the top box and the bottom of the joist. With the ceiling height established so that there is ample air space over the eighth layer of boxes but not room enough for a ninth layer (fig. 6), it is not necessary to depend upon close supervision of workmen during loading to prevent stacking too close to the ceiling.

Provision is made in the basement for a slatted false floor with space for air circulation underneath (fig. 6). This false floor was to prevent ground heat from directly penetrating the bottom boxes.

At the time of the tests it had not been installed because of difficulty in getting material. The design also calls for rails along the outside walls of each room to prevent workmen from stacking boxes directly against the wall (fig. 6). When installed, they will reduce further the necessity for supervision.

MANAGEMENT OF HARVESTING, STORING, AND MARKETING

As already outlined, the new cold-storage plant, in which careful attention was given to pertinent details of construction, is only a segment of a broader program of improved fruit handling. The harvesting, packing, storing, and marketing operations were to be interrelated, with the final objective that of getting high-quality fruit to the consumer. The first step in setting up the actual schedule of operation was an association meeting at which the plans for the entire program were discussed. Here the growers acquired a thorough understanding of procedures and objectives, so they were sympathetic and cooperative with all phases of the program. It was arranged that returns from the sale of fruit would be pooled by varieties.

If fruit returns had not been pooled it might have been necessary to make some adjustments in storage, warehousing, precooling, and other charges, according to the service performed on each grower's lots. Adjustment or variations in service-charge rates are best settled in advance of the harvest season and before any arbitrary fruit segregations have been made.

Provision had to be made for the actual allotment of space in storage and the control of fruit deliveries into the plant. This responsibility was given to the plant foreman. He had to see that all apples were put in the right place, that the refrigeration was distributed properly, and that deliveries of each class were so arranged as to avoid confusion in the storage and packing rooms. During certain periods of the harvest season fruit of all classifications would probably be delivered at the same time.

The marketing program, so far as it could be controlled by the shipper, was to conform to specified allocations. Some adjustment of the scheduled shipments was expected during the season, caused by unforeseen market demands or inadvertent misassignment of fruit to wrong blocks. Nevertheless, it was agreed that sales and deliveries would proceed in the order set up for three classes of fruit, in early, intermediate, and late blocks.

It was agreed that, as the picking season approached, all orchards would be visited and the fruit classified. This would place the apples in the three categories, depending upon the time they were to be shipped to market.

EARLY BLOCK

Fruit designated to be shipped early included that produced on orchards or parts of orchards having a light crop that tended to be large-sized, nonuniform in maturity, water-cored, sunburned, and otherwise abnormal. Shortage of labor has usually made it impossible to pick all fruit at optimum maturity; however, limitations on storage space and handling facilities prevented taking care of the entire crop even if it could have been picked at optimum maturity. It was anticipated therefore that a substantial percentage of the crop would be picked in a stage of advanced maturity, be forced to remain in the orchard at high fall temperatures, or would not be given adequate refrigeration. None of this fruit would be suitable for late storage and all would be allocated to the early-shipment block.

These apples were the first to be packed, directly upon being received from the orchard, from temporary storage on receiving platforms, or from a room adjacent to the packing room from which the cold air had been diverted. Insofar as railroad cars were available the packed fruit was to be shipped immediately and refrigerated only in transit. If delivered promptly to consumer outlets it would be received while still in good condition. This block constituted about a third of the Delicious crop.

INTERMEDIATE BLOCK

The Delicious apples allocated for shipping during the intermediate season were to be of good quality at the time of picking. They were to be cooled as promptly as the refrigeration capacity would permit, using only the capacity not required to cool properly the late-shipment fruit. The apples were to be packed from cold storage after the early-shipment fruit had been cared for, then held in storage for variable periods. As the late-shipment fruit was packed, certain lots were to be withheld and sold also in the intermediate period.

The fruit of each classification was to be stored in separate rooms so far as possible. When late-shipment apples were being received, it was expected that about three-fourths of the total refrigeration capacity would be diverted to them in the two basement rooms. Fruit received in these rooms was to be cooled to 30° to 32° F. within 7 days. Intermediate-shipment fruit would be received on the first floor and be given but a small part of the cooling capacity of the plant. Soon after the late-shipment apples were in storage, the cold air would be distributed in greater proportion to the upper floor and be used to cool the intermediate-shipment fruit before and after it was packed. This block made up about one-third of the Delicious crop.

LATE BLOCK

Orchards or parts of orchards producing fruit uniform in size, maturity, tree load, and color and of the highest quality were to be picked at the optimum stage of maturity and the apples given preferred handling at all times and kept in storage for late market. They were to be placed in storage rooms and cooled promptly. An effort was to be made to deliver this fruit to the warehouse within 24 hours after it had been picked, preferably each morning. This schedule allows cool night temperatures to remove some of the heat from the fruit. These late-shipment apples were to be cooled loose in boxes and packed after the other fruit had been taken care of, being held at 30° to 32° F. until time of shipment.

During the packing operation, any lots or partial lots of poor-quality fruit that might have escaped notice when received or that might have developed off-condition in storage were to be withdrawn from the late-storage block and shipped as soon as possible. It was recognized that some delays would occur in packing. Extra large sizes might remain in the bins longer than the other sizes, and "C" grades would be held in the packing room if facilities became crowded, while more uniform lots of intermediate sizes were being taken care of. At the higher temperatures maintained in the packing room, this fruit would ripen too much for long storage. So "C" grades and the larger sizes of other grades that had not had prompt handling were also to be withheld from the late-shipment group. About one-third of the Delicious crop was to be assigned to this block.

Observations on Storage-Plant Performance

During two seasons of operation temperature and air velocity readings were taken in the plant. In the first season the distribution of air was checked particularly and changes were made in the duct openings. The plant was not ready when the harvest began—the first apples were brought in on September 23 and the refrigeration was turned on October 10. The fruit temperatures recorded, therefore, were not typical, so those taken the following season were used for analyzing plant performance.

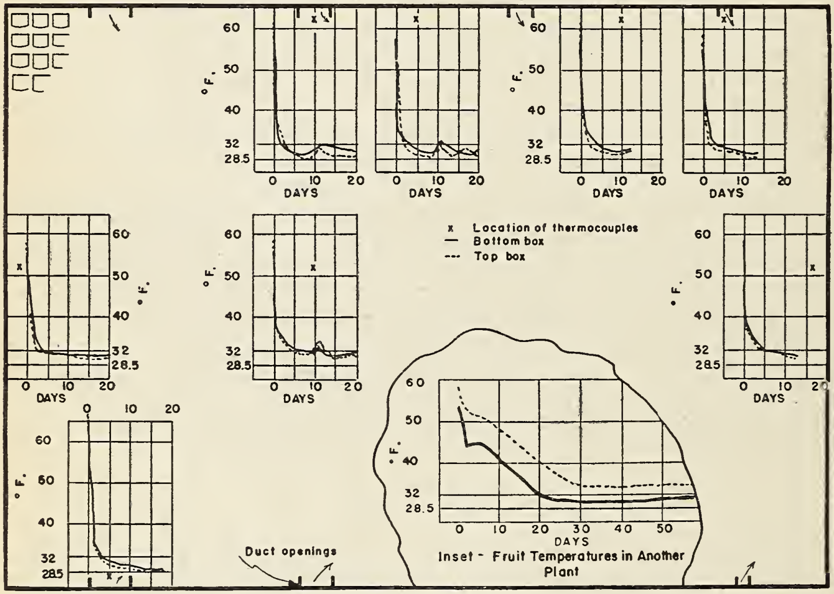


Figure 7.—Fruit temperatures in room 1 (basement). Apples were loose in field boxes, and thermocouple positions were located in the room as indicated by the positions of cross marks (x). Air-duct openings are shown at each side of the room. Comparative temperatures are shown for another plant in a preceding year.

Soon after the blower was started the air velocities were measured at each opening to note evenness of distribution. It was found that the scoops inside the ducts at the openings would divert the right volume of air on delivery only when the upstream side of the opening was rounded to give smooth flow (fig. 4, *A*). Otherwise, turbulence in the air stream choked down the delivery. Also, where the air stream turned downward into the vertical shaft extending to the lower room, the air tended to pile up on one side. The valve at the bottom of the shaft, which divides the air between the two basement rooms, had to be set to one side of center to give equal flow to the two rooms. Guide vanes at turns in the ducts were found important not only in keeping down resistance but also in permitting even division of the air between rooms.

The air ducts had been installed without diffusion baffles under the openings, so when there were no boxes of fruit below them the delivery air went straight down and spread out over the floor. After the diffusion baffles were installed the air was spread out near the ceiling and diverted in all directions. A secondary air movement was observed to be induced from under the baffles. This probably accounted for the slightly faster rate of cooling at the sides of the room as compared with the center aisle.

Thermocouples were inserted in apples in the centers of boxes as they came from the orchard to be placed in storage. The wires extended to an accessible point in the aisle so that fruit temperature readings could be taken at any time without disturbing the stacking. Temperatures were taken in top and bottom boxes in various parts of the rooms. The rates of cooling in field boxes in the two basement rooms are shown in figures 7 and 8. This fruit was to be held for late shipment and had to be cooled quickly.

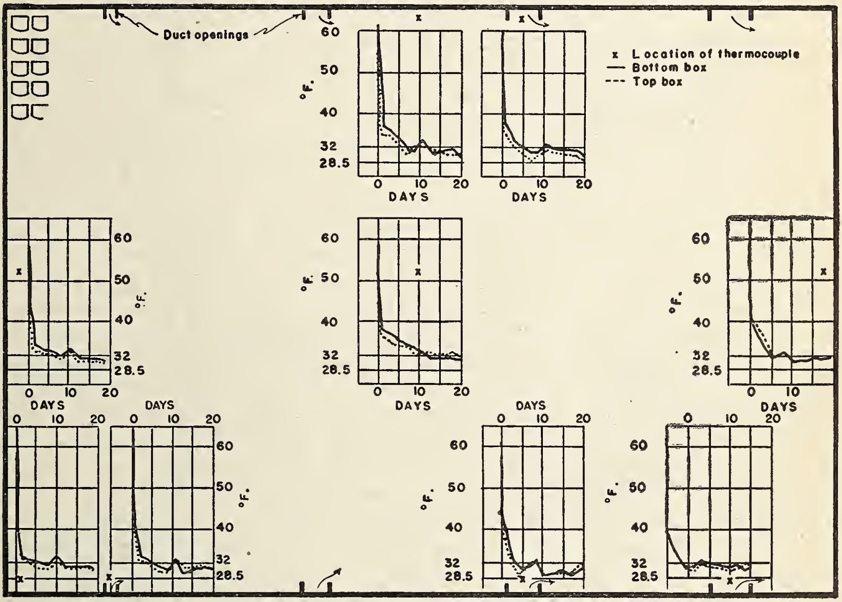


FIGURE 8.—Fruit temperatures in room 2 (basement). Apples were loose in field boxes, and thermocouples were located in the room as indicated by the positions of cross marks (x). Air-duct openings are shown at each side of the room.

During the period for which temperatures are shown, most of the refrigeration for the plant was diverted to these rooms. The charts show that the top and bottom boxes in each location cooled about equally. In general, the apples along the sides of the rooms reached 32° F. in about 3 days; those along the center aisle, in about 5 days, with the exception of the boxes at one point near the center of the aisle. These are discussed on page 22. Most of the field heat was removed from all the apples within the first day. This is in contrast to storages in which air circulation may be inadequate or in which an attempt is made to cool all the fruit receipts with insufficient refrigeration. When Delicious apples remain at temperatures above 50° for several days and reach 32° only after several weeks in storage, or not at all, they have lost too much of their life to be held satisfactorily for late marketing.

The inset in figure 7 shows fruit temperatures taken in another plant in an earlier year. The slow rate of cooling and the failure of some of the fruit to reach 32° F. even after a month in storage are typical of what may be expected in plants designed and operated without specific attention to caring for the long-storage fruit. Such temperatures, particularly after the picked apples have been in the orchards for several days, take the life out of the fruit. It may be in excellent condition for the early market but becomes mealy if held very long.

Such slow rates of cooling may be the result of several factors: (1) Use of packed rather than loose boxes, (2) inadequate air circulation, (3) varying temperatures in different parts of the room, (4) slow air velocity, (5) obstructions to air movement, (6) ducts so laid out that too little air reaches part of the room or that the return duct is not picking up the warmest air, and (7) attempting to cool more fruit than the refrigerating equipment can care for.

Most of these difficulties were avoided in the Oroville plant, and the apples cooled promptly to good storage temperatures. Some details were overlooked, however, as figure 8 indicates. The apples at the center of the aisle in room 2 cooled more slowly than those at other positions. Their temperature quickly fell below 40° F., but it was about 12 days before it reached 32°. This illustrates the effect of air leakage in a storage room. These boxes were stacked next to a conveyor that passed through the floor to the room above. There was a housing around the opening in the floor, but the end of the housing where the conveyor entered the upper room was open to permit boxes to pass. It was intended that this opening should be closed with a removable door when the conveyor was not in use. A canvas curtain was to be hung over the opening so that when the door was taken off very little air would pass. Boxes moving along the conveyor would push through the curtain, which would immediately drop back in position. Because of the pressure of other things needing attention, neither the door nor the curtain were installed. The result is apparent in the temperature record. Even at the wall opposite this opening, the cooling was a little slower than at other points along the wall.

Several of the temperatures were taken in boxes along the wall, halfway between and directly under openings. Although the openings along the ducts were about 24 feet apart, figures 7 and 8 show that apples at points between openings cooled almost, if not fully, as fast as those directly below. With the exception of the area affected by the open conveyor housing, the apples throughout the room cooled to 32° F. or below within 6 days.

Apples precooled in field boxes were left in place until other fruit had been packed. They were then moved to the washing, sorting, and packing line and again put in the cold-storage rooms. During this process, they warmed up to about 40° and 45° F. By this time no hot fruit was being brought into the building, so there was sufficient refrigeration for all four rooms. The air in them was now moving in equal proportion, so that the basement was no longer receiving most of the refrigeration. The apples, wrapped and packed tightly in boxes, did not give up their heat so readily as when in loose boxes. The storage rooms were partly filled with apples already cooled to 30°, and air temperatures as low as those used earlier in the season might have caused some freezing. In these circumstances the rate of cooling was distinctly slower than before.

Temperatures during this period at various points in one upper and one basement room are shown in figures 9 and 10. In this case it took from 10 to 15 days for the fruit temperatures to reach 32° F., but that of most of the box centers was reduced to 34° or 35° within 5 days. The packed fruit cooled at a fairly uniform rate along the walls, and, as was the case with loose fruit, the aisle temperatures did not drop so fast. The rates of cooling were about equal in the two rooms and in top and bottom boxes. The temperatures charted in figures 9 and 10 are those taken only during the period immediately following packing, although readings were made until the fruit was removed.

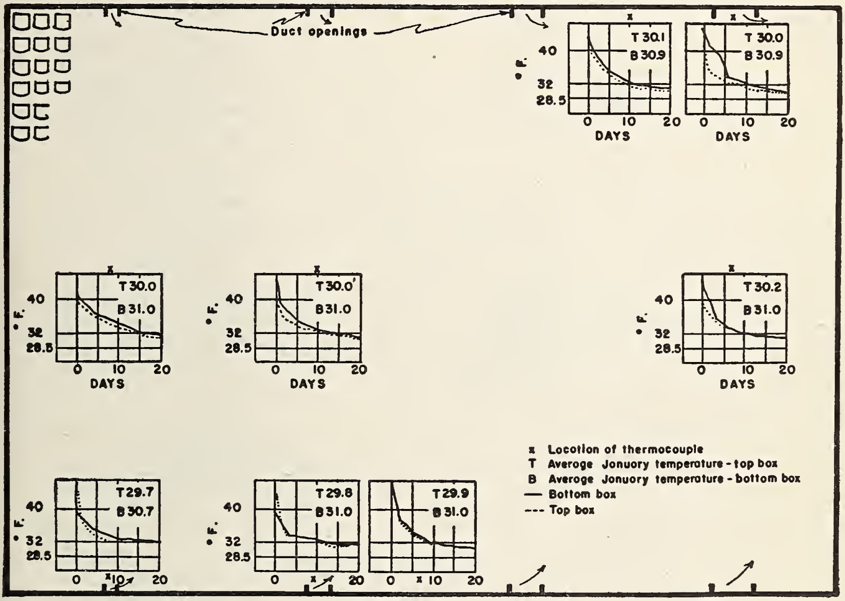


FIGURE 9.—Fruit temperatures in room 2 (basement). Apples were packed in lidded boxes, and thermocouples were located in the room as indicated by the positions of cross marks (x). Air-duct openings are shown at each side of the room.

In addition to prompt cooling, low temperatures during storage are important for Delicious apples that are to be held for late shipment. To provide low temperatures throughout a room without causing freezing at some points requires good air distribution. To compare temperatures at various locations after the fruit had cooled, the average taken during January for each location is inserted in figures 9 and 10. The widest variation from time to time at any one location during this period was 1.2° F. In the upper room the average fruit temperatures at all positions were within 0.3° of 30°. There was a slight tendency for the top layer to be cooler than the bottom, although the widest difference at any location was 0.3°.

In the basement room the top-box temperatures were also within 0.3° of 30° F., but the bottom boxes were from 0.8° to 1.2° warmer. This was not serious, since the warmest fruit was about 31°, but it does show the effect of placing the boxes directly on the basement floor. The thermocouples were in the center of the box. No doubt the apples in the lower layers of the bottom box were warmer. Even with the pumice insulation, there was heat rising from the ground. With no air circulation under the boxes this heat went directly into the fruit. Tests in other plants have shown that slatted floor racks (fig. 6) permitting free air circulation between the floor and the boxes would have carried this heat away. Such floor racks are necessary only on the basement floor because the under side of the upper floor is as cold as the room itself. In a ground floor, however, heat passes up through the floor even though it is insulated. Floor racks are planned for the basement rooms in the Oroville plant and will be installed when material becomes more readily available.

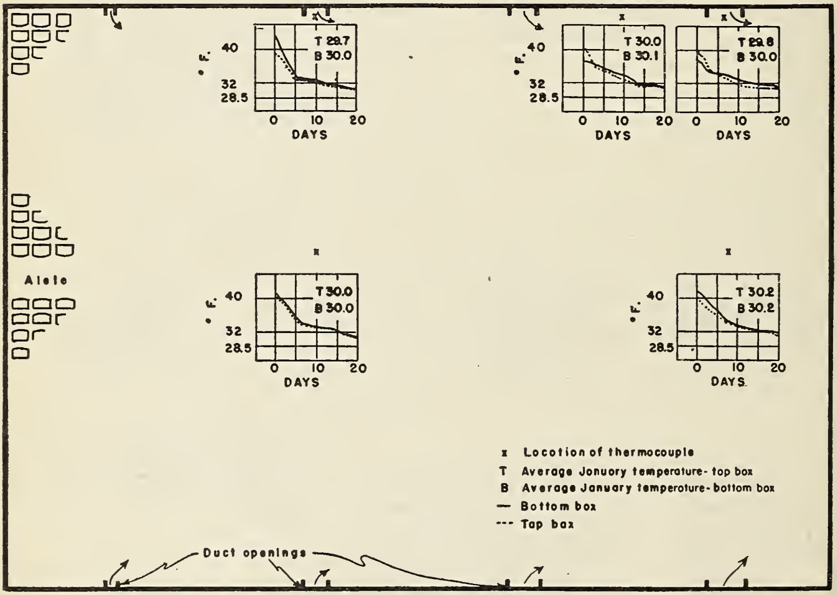
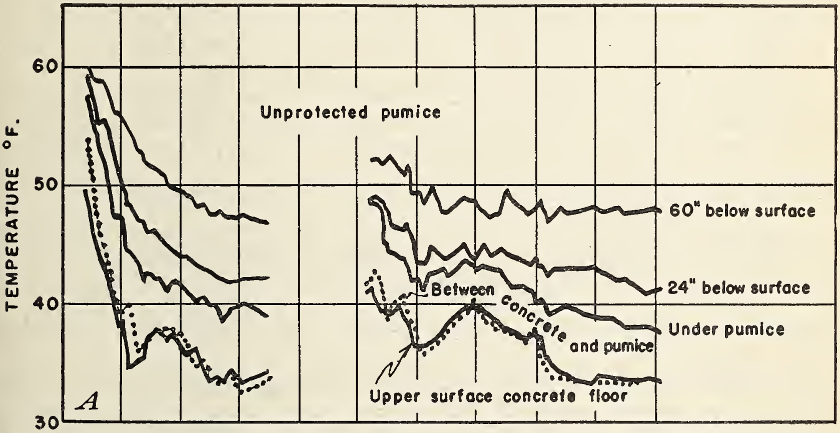
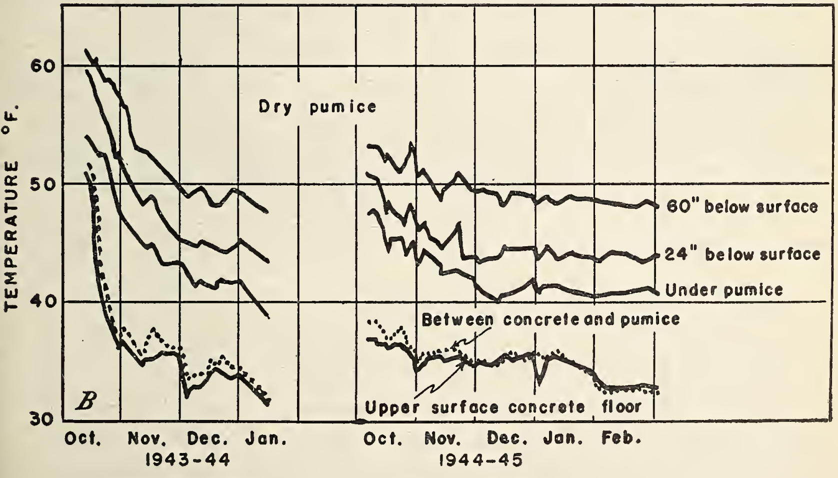


FIGURE 10.—Fruit temperatures in room 3 (upper floor). Apples were packed in lidded boxes, and thermocouples were located in the room as indicated by the positions of cross marks (x). Air-duct openings are shown at each side of the room.

When the building was constructed, thermocouples were buried in the ground under the floor to permit comparison of two pumice installation methods. This material was taken from natural deposits and contained moisture. Under most of the floor a 6-inch layer was placed below the 4-inch concrete slab. In one area about 14 feet square, however, the pumice was dried before installing, and a layer of asphalt roll roofing was put under it to prevent the upward movement of ground moisture. Since the ground-water level is only a few feet below the basement at Oroville, capillary movement of moisture might be expected to keep the pumice wet. In this area only 5 inches of pumice was used. Five thermocouples were buried in the floor, one just under the surface of the concrete, one just under the concrete on top of the pumice, one at the bottom of the pumice, one at 2 feet below the floor surface, and one at 5 feet below. Another set was installed in a similar manner at a point in the floor not underlain by roofing and with a 6-inch layer of naturally moist pumice. Temperatures at these 10 points were taken periodically over 2 seasons. The results are shown in figure 11.



PUMICE, 6 INCHES



DRY PUMICE, 5 INCHES

Figure 11.—Temperatures in the floor and ground during parts of two seasons, the floor insulated (*A*) with 6 inches of naturally moist pumice and (*B*) with 5 inches of dried pumice, protected from moisture by a layer of roll roofing.

Temperatures at the top and bottom of the 4-inch concrete slab were nearly the same all the time, as concrete is a good conductor of heat. There was a substantial difference in temperature however, between the top and bottom of the pumice. The relative difference depends upon the insulating value of the material. The thicker the pumice the greater would have been the difference.

The temperature difference between the top and bottom of the pumice was greater for the dry material than for the wet (fig. 11). The temperatures were changing continually, so an accurate measure of the difference in effectiveness between the wet and dry pumice could not be made. During December of the first season and February of the second, however, the temperature changes were relatively small, so these periods can be used for an estimate. The average temperatures during December 1943 and February 1945 at each point in and under the floor are shown in figure 12.

In December 1943 the temperature difference through the wet pumice was 5.3° F. and from the bottom of the pumice to the 5-foot depth, 8.2°. Thus the 6-inch thickness of pumice was $(5.3/8.2)=0.65$ as good an insulator as 50 inches of soil. Each inch was equivalent to $\frac{0.65\times 50}{6}=$ 5.4 inches of earth. At the same time, the temperature difference through the dry pumice was 7.2° and through the earth below, 7.1°, indicating that the dry pumice was $(7.2/7.1)=1.01$ times as good as 51 inches of soil, each inch being equivalent to $\frac{1.01\times 51}{5}=10.3$ inches of soil. Thus the dried pumice was $\frac{10.3}{5.4}=1.9$ times as effective as the wet pumice. A similar analysis the second season shows the dry pumice to be 2.8 times as effective as the wet.

The difference in effectiveness between the wet and dry pumice was substantially greater the second season. This indicates that the wet pumice may have become even wetter by absorption of ground water,

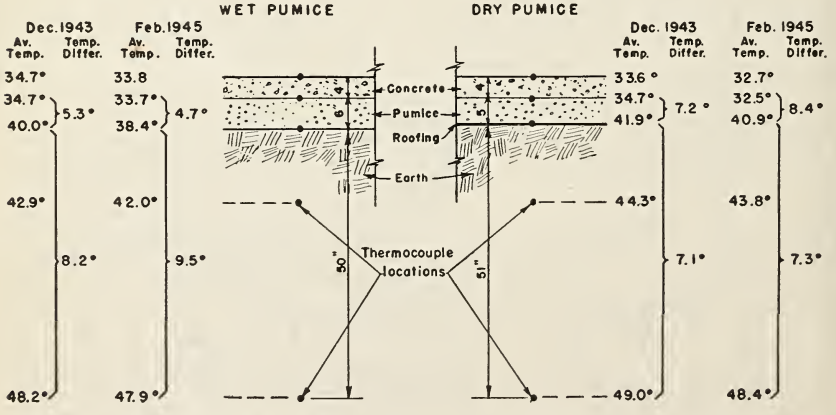


FIGURE 12.—Sections of floor and earth in two locations in cold-storage room, showing average temperatures at various depths. The section illustrated on the left had a 6-inch layer of naturally moist pumice gravel; the one on the right, a 5-inch layer of dried pumice gravel and a protective sheet of roll roofing to keep it dry.

while the other section was kept dry by the roofing layer. Although these comparisons are based on fluctuating temperature conditions and are therefore not exact, it seems safe to conclude that the insulating value of pumice protected underneath by a layer of vaporproof material, such as asphalt roll roofing, becomes at least twice as effective as the unprotected, with ground water conditions as they are at Oroville.

During January 1945, when the boxes were removed from the floor, the temperature of the top surface of the concrete dropped 2° or 3° F. When the boxes were on the floor the top of the concrete remained at more than 37° above the wet pumice and at more than 35° above the dry. After the boxes were removed it cooled to between 32° and 34°. This is further indication of the undesirable effect of setting boxes directly on the floor instead of on floor racks. Except for a short period when there were no boxes on the wet pumice floor and the other floor still had fruit stacked on it, the surface of the concrete where the pumice was protected from ground moisture was cooler at all times.

To avoid overloading the cooling equipment, apples going into cold rooms for late storage were brought to the plant in the morning. It was sometimes necessary, however, to accept some fruit into cold storage in the afternoons. The apples were found to be enough cooler in the morning to make limiting afternoon deliveries worth while, especially during the early part of the season. In 1943 a large number of fruit temperatures were recorded upon arrival at the plant. Each day the average of those taken during the morning were compared with those taken in the afternoon. The results are shown in table 2. On one day the difference amounted to more than 18° F. It will be seen that as long as the maximum atmospheric temperature was above 70° the apples were usually more than 10° warmer in the afternoon than in the morning.

Observations on Management Plan

To begin the 1944 harvest season, the association was equipped with a plant that had a total storage capacity of 84,000 packed boxes and a cooling capacity of approximately 4,000 loose boxes per day. To be handled through these facilities was a crop that ultimately amounted to 206,123 loose boxes, of which 154,099 were of the Delicious, a variety that should be picked and cared for in 2 weeks.

At the beginning of harvest each grower's orchard was visited and classified according to quality of fruit into early-, intermediate-, and late-shipment blocks. About one-third of the Delicious tonnage was placed in each.

Picking the earliest apples (McIntosh) began on August 29, and although the harvest was only 2,342 packed boxes, it served to start operations. Refrigeration equipment was turned on, packing equipment was started, and growers enrolled their picking crews and made final arrangements for hauling their fruit to storage.

By the time the Delicious harvest began, on September 19, the storage rooms had been cooled to minimum temperatures. The valves in the main ducts were adjusted to divert approximately three-fourths of the air volume to the two basement rooms. All late-storage fruit was received loose in boxes in these rooms and cooled promptly to 30° to 32° F. Sufficient air was supplied to the two top rooms to maintain satisfactory air temperatures, although the rate of cooling there was much slower. It is important to note at this point that low air temperatures in the storage rooms are not necessarily an indication of satisfactory cooling. The rate of air movement may be so low in some parts of the room that the fruit cannot be cooled in a reasonable time.

TABLE 2.—*Core temperatures of apples received in the morning and in the afternoon for storage at Oroville, Wash., 1943*

Date	Core temperature of fruit			Atmospheric temperature	
	Average morning temperature	Average afternoon temperature	Difference	Minimum	Maximum
	° F.	*° F.*	*° F.*	*° F.*	*° F.*
Sept. 23	64. 3	71. 8	7. 5	46	81
24	58. 8	71. 0	12. 2	45	83
25	53. 0	66. 8	13. 8	48	82
26	58. 0	69. 5	11. 5	49	83
27	51. 5	62. 5	11. 0	45	75
28	46. 7	60. 7	14. 0	39	76
29	49. 8	64. 0	14. 2	45	78
30	50. 8	67. 7	16. 9	43	76
Oct. 1	50. 4	67. 9	17. 5	42	79
2	49. 0	67. 7	18. 7	45	81
4	55. 3	62. 6	7. 3	48	75
5	63. 0	64. 0	1. 0	59	72
6	62. 5	69. 3	6. 8	57	76
7	54. 3	67. 1	12. 8	47	77
8	51. 5	69. 2	17. 7	46	78
9	56. 5	60. 2	3. 7	50	66
11	56. 0	61. 0	5. 0	52	64
12	44. 3	49. 3	5. 0	37	54
13	41. 5	53. 0	11. 5	35	62
14	39. 3	54. 4	15. 1	32	65
15	49. 8	58. 2	8. 4	44	62
16	41. 6	51. 0	9. 4	36	60
19	37. 2	43. 8	6. 6	30	56
20	42. 2	52. 0	9. 8	36	58
21	44. 0	45. 7	1. 7	39	49
22	40. 4	42. 8	2. 4	35	49
23	35. 8	40. 2	4. 4	30	47
25	44. 6	50. 3	5. 7	41	59
26	44. 0	48. 3	4. 3	43	56
27	47. 2	49. 0	1. 8	44	55
28	46. 1	46. 4	. 3	42	52
29	44. 8	44. 7	—. 1	43	48
30	36. 8	42. 0	5. 2	31	53
Nov. 1	33. 3	39. 0	5. 7	29	50
2	33. 0	39. 7	6. 7	29	43
3	31. 6	39. 7	8. 1	35	48
4	37. 2	42. 5	5. 3	39	51
5	39. 4	42. 5	3. 1	33	56
6	35. 0	40. 3	5. 3	27	51
8	36. 0	42. 0	6. 0	32	54
9	35. 0	43. 7	8. 7	28	49
10	35. 8	40. 5	4. 7	36	52

Since the function of air movement is to transport the heat from the fruit, it is important that it be rapid and uniform throughout the room.

Fruit was packed over the grader at the rate of approximately 2,000 packed boxes a day, and, on peak days, as many as 2,800. It was intended that the early-block apples would be shipped as fast as packed—about two and one-half cars a day. Instead, however, an average of only one a day was shipped during that period. As the season progressed, fruit shipments gradually caught up with the predetermined shipping schedule. Except for part of a car shipped March 7, all apples of the Delicious variety were marketed and out of storage by February 20. All fruit was shipped by March 7, and the refrigeration equipment was then turned off.

It was fortunate that preharvest planning had been done, for the 1944 harvest and packing season presented some conditions, caused primarily by the war, that made the entire operation hazardous and difficult. A shortage of labor in the orchards prolonged the picking season. A greater proportion of the fruit than was desirable was picked at a stage of overmaturity. In all operations inexperienced or incompetent labor, or both, made it difficult to obtain proper care of fruit or to observe the details of operation as was planned. Shortage of boxes in which to harvest the fruit delayed nearly all growers in their picking. Some of the apples originally designated to be held for late shipment could not be picked at optimum maturity. It was most difficult to obtain sufficient warehouse labor to receive the fruit as fast as delivered. Delay in waiting to unload fruit at the warehouse kept growers away from their orchards at times when close supervision of picking operations was necessary.

In some periods it was impossible to obtain enough fruit packers, and as a result the daily output was reduced. The shortage of boxes made it necessary to use various types of paper containers for the packed fruit. This introduced problems in packing, conveying, lidding, trucking, and stacking in storage. Perhaps the most serious problem, however, was the shortage of refrigerator cars in which to ship the fruit to market.

The congested condition of the storage made it difficult to keep fruit lots separate. As a result, some early and intermediate fruit was lost and reached an advanced stage of ripeness before being shipped. Thus, throughout the season, it was necessary to adjust and modify the original plans of the segregation program to meet circumstances, and the adjustments were usually compromises rather than improvements.

Operational Observations

A number of operational observations should be emphasized in relation to the plan of organization. The fruit segregation program was implemented by the fact that the association pooled its returns from sales. The fruit, received in loose boxes, was kept separate in storage by grower's lots until packed. During packing a record was kept of the number of boxes by size, grade, and variety and credited to the individual grower. All fruit thereafter was stored or shipped by pools. Pools may be arranged by period of shipment, variety, grade, size, or by combinations of these. In no case was a grower's fruit kept separate after packing.

This method of pooling, however, did not preclude the possibility of one grower's fruit receiving treatment different from another's prior to packing. For instance, there was some objection by a few growers who were asked to hold in the orchard fruit that was classed as early or midseason blocks. They were fearful that such delay would cause deterioration and increase cullage, thereby reducing their total pack-out and perhaps lowering the grade of their packed fruit. To meet this objection, the association agreed to prorate any financial losses to a grower against all fruit pools, but none occurred.

It is not the intention to imply that a fruit-segregation program cannot be carried on without pooling. The success of any program is based upon a number of factors. Although they may vary in importance from one organization to another they involve:

1. Careful advance planning for each season.
2. Complete coordination and cooperation of growers and management.
3. Vesting entire responsibility and authority in one person, delegated to spend full time on carrying out the program.

Under actual operation it was found that coordination and cooperation were based primarily upon a thorough understanding by growers and employees of what was being done. The growers, especially, had to interpret the extra attention required of them in terms of the improvement of the quality of the fruit as it goes to market. Since all who were affected by the segregation program had this understanding and properly interpreted the primary objective of their efforts, the problems in coordination and cooperation were easily solved.

It was found to be highly important to place the responsibility for the segregation program on one man as a full-time task. He had to have a thorough knowledge of each grower's crop and keep informed on harvesting operations as the season progressed. He had to be responsible for the preharvest planning of picking, hauling, and storage operations and, so far as circumstances permitted, had full authority to perform these operations in conformity with the plans.

Under the preharvest planning program each grower was given a schedule for delivering fruit to the plant. Orchard operations then progressed more smoothly because each grower knew about when his apples would be taken care of and could devote more time to supervising the picking.

Another operational observation pertains to the problem of getting the fruit hauled from the orchard to the warehouse and cold storage. To a large extent, commercial haulers were employed to serve several growers at a time. They were normally paid by the box and were interested primarily in quickly hauling as much fruit as possible. Having no interest in a segregation program they would often haul the wrong blocks of fruit from the orchard and would sometimes deliver it to the wrong storage rooms. This imposed a heavy burden on growers and storage crews alike. There seemed to be no logical solution to this problem so long as commercial haulers were employed.

In view of this experience the following plan is suggested although it was not carried out in connection with these studies. Many fruit firms have developed and employed similar plans successfully. It is based upon the associations assuming the responsibility of hauling the fruit from the orchard. This could be done by outright ownership of trucks or acquiring them on a rental basis from grower members and others. The trucks would be so operated by the association as to facilitate the segregation program.

The arrangement would relieve the grower of the responsibility for hauling his fruit and enable him to spend full time in the supervision of harvesting operations. This would be additional assurance that the fruit would be kept segregated throughout the handling and storage procedure. Moreover, trucks operated by the association could be pooled in hauling the fruit in greatest need of attention. This plan provides flexibility of operation and, as used by other associations, permits adequate and timely attention to all hauling needs.

RESULTS OF THE STUDY

One of the objectives of this study was to observe the operation of a plan of preharvest scheduling and segregation of apples for shipment during early-, midseason-, and late-marketing periods and determine whether it could be used effectively in a typical organization. Although wartime conditions prevented following out the plan in all its details, the 2 years of operation demonstrated that a preharvest plan for handling, storing, and marketing is both worthwhile and practicable. Some of its advantages are that it—

1. Organizes harvest operations in the orchard, with emphasis on better supervision.
2. Coordinates picking and hauling operations with plant, warehouse, and storage capacity.
3. Provides systematic and orderly receipt of fruit at the warehouse.
4. Conserves refrigeration for fruit intended for storage.
5. Simplifies warehouse segregation and packing procedures.
6. Facilitates careful planning in the arrangement and operation of all facilities, including packing, storing, conveying, receiving, and loading; reduces office work; and increases the efficiency of the entire operation.
7. Assures fruit in good condition for shipment during the whole marketing season.

To obtain these advantages it is of course necessary that—

1. Each grower conduct his harvesting and marketing operations in conformity with the general plan.
2. All operations be carefully planned and well managed.

The cold-storage and packing facilities were very satisfactory. Promptness and uniformity of getting and maintaining optimum fruit temperatures were better than observed in any other plant where comparable records were taken. The factors given special consideration in these facilities are:

1. Adequate refrigeration for the heat load to be imposed.
2. Large air volume per unit of refrigeration.
3. Air delivery to rooms and return near ceilings.
4. Continuous clear space for air circulation at ceilings, not blocked by boxes or girders.
5. Maximum air travel and velocity between delivery and return ducts.
6. Automatic reversing of air direction in rooms, whereby each duct serves alternately for delivery and return.
7. System of dampers whereby all or any part of the air supply can be directed to any room or combination of rooms.
8. Provision for uniform air circulation throughout the stacked fruit.
9. Minimum of turbulence and low static pressures, afforded by large streamlined ducts and apertures in them.
10. Use of air temperatures slightly below the freezing point of fruit without danger of freezing (26° F. air was used at the Oroville plant).

11. Diffusion baffles for uniform air distribution and protection of fruit from freezing.
12. Provision of insulation necessary to economical refrigeration, including use of inorganic pumice stone under concrete basement floor as insulation material.
13. Simplified and efficient conveyor system, whereby fruit can move freely in either direction between receiving, packing, and storing points and car loading.
14. Arrangement of storage, packing, receiving, car loading, office, refrigeration, and other services to obtain maximum convenience and efficiency of operation.
15. Provision for future expansion of facilities without sacrificing present efficiency.

Of all the design factors given special attention, perhaps the most encouraging was the principle of reversed air movement. Fast cooling and uniform low temperatures being of primary importance, this method of air distribution is practical, economical, and effective. Whether or not a plant is designed for reversing the air movement, however, each of the factors listed above contributes to uniform cooling and most effective application of refrigeration.

On the whole, the observations made at this plant demonstrate that the application of a well-organized fruit-handling plan to a storage and packing plant designed and operated to facilitate the plan can be a means by which groups of growers can better assure themselves of the highest quality of apples during the entire season.

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